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Title: Additive Manufacturing for Ceramics

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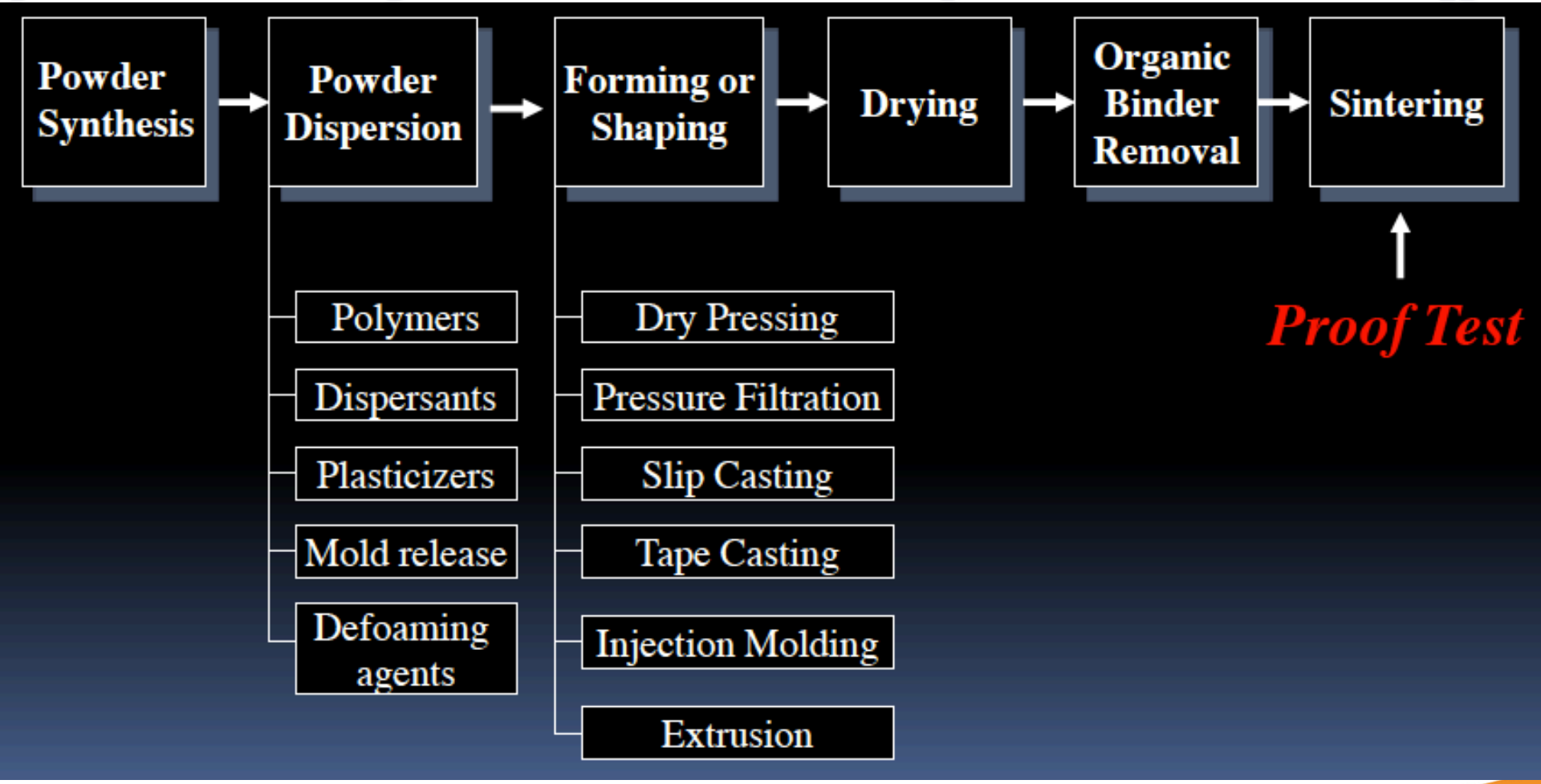
Additive Manufacturing for Ceramics

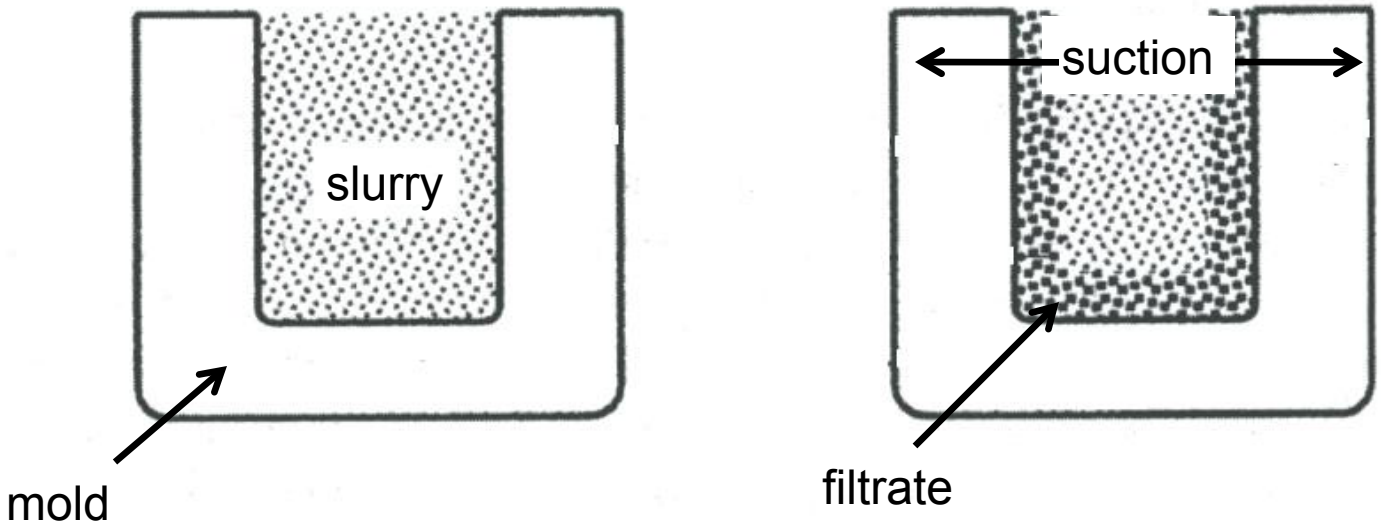
The longstanding dream



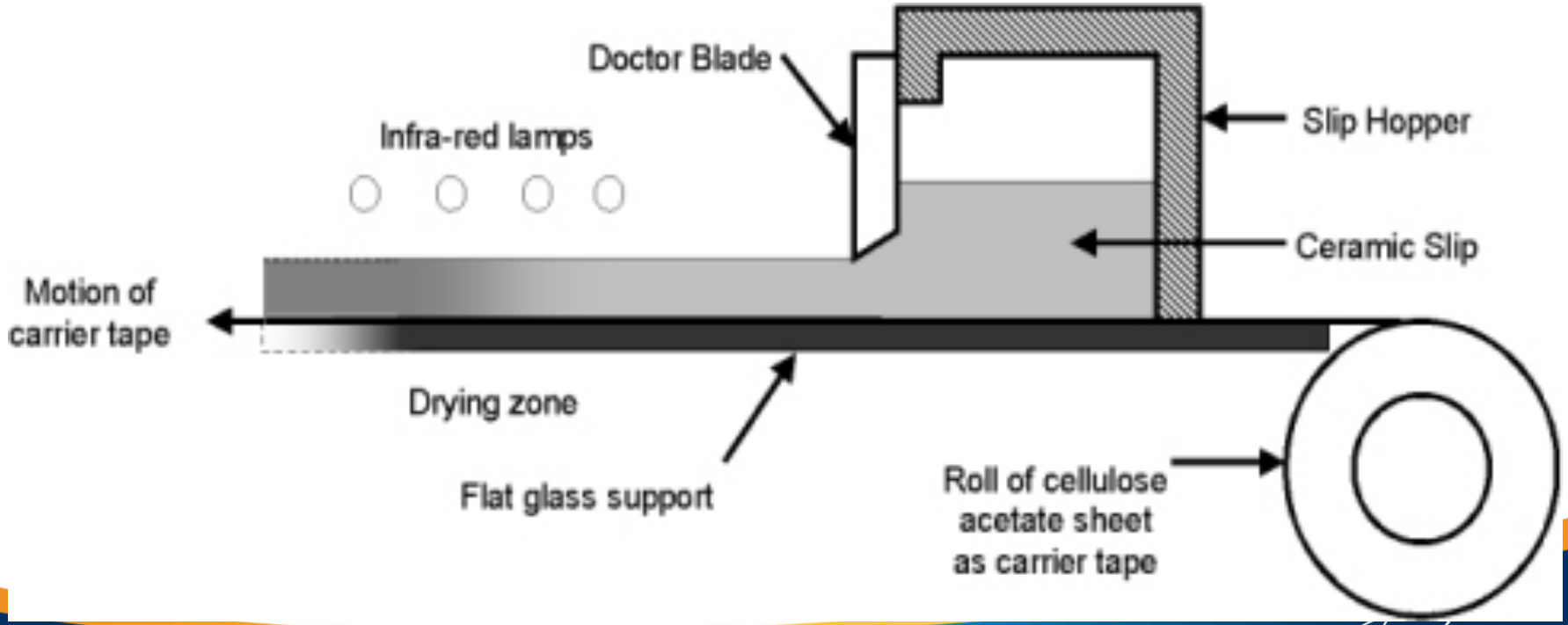
Ceramics considerations

- While several methods have been demonstrated for ceramics; commercial availability of equipment is more limited
- AM for ceramics is focused on the dispersion & forming steps; post processing is still required of green parts
- Robocasting
- No AM ceramic capability currently at the lab

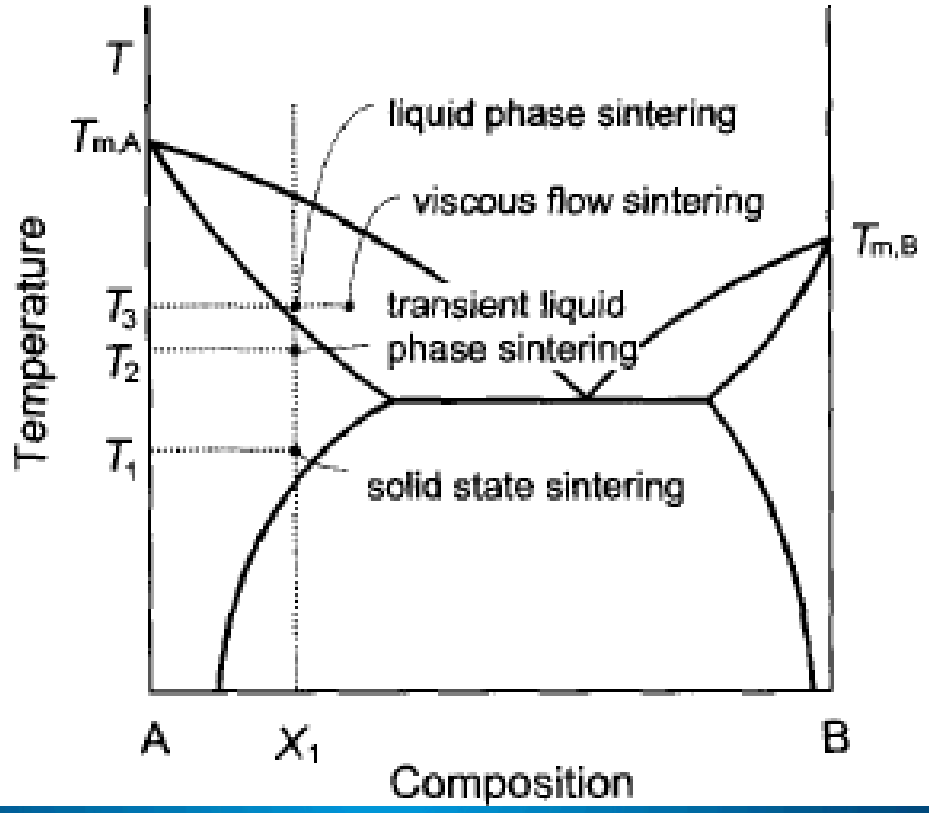
- **Slip Casting** involves pouring a ceramic slurry into a mold. Once in the mold, the ceramic slurry is dried by the removal of the liquid through the gypsum mold via capillary forces. Water is the liquid of choice in slip casting. The green body left behind in the mold after removal of the liquid is then sintered.



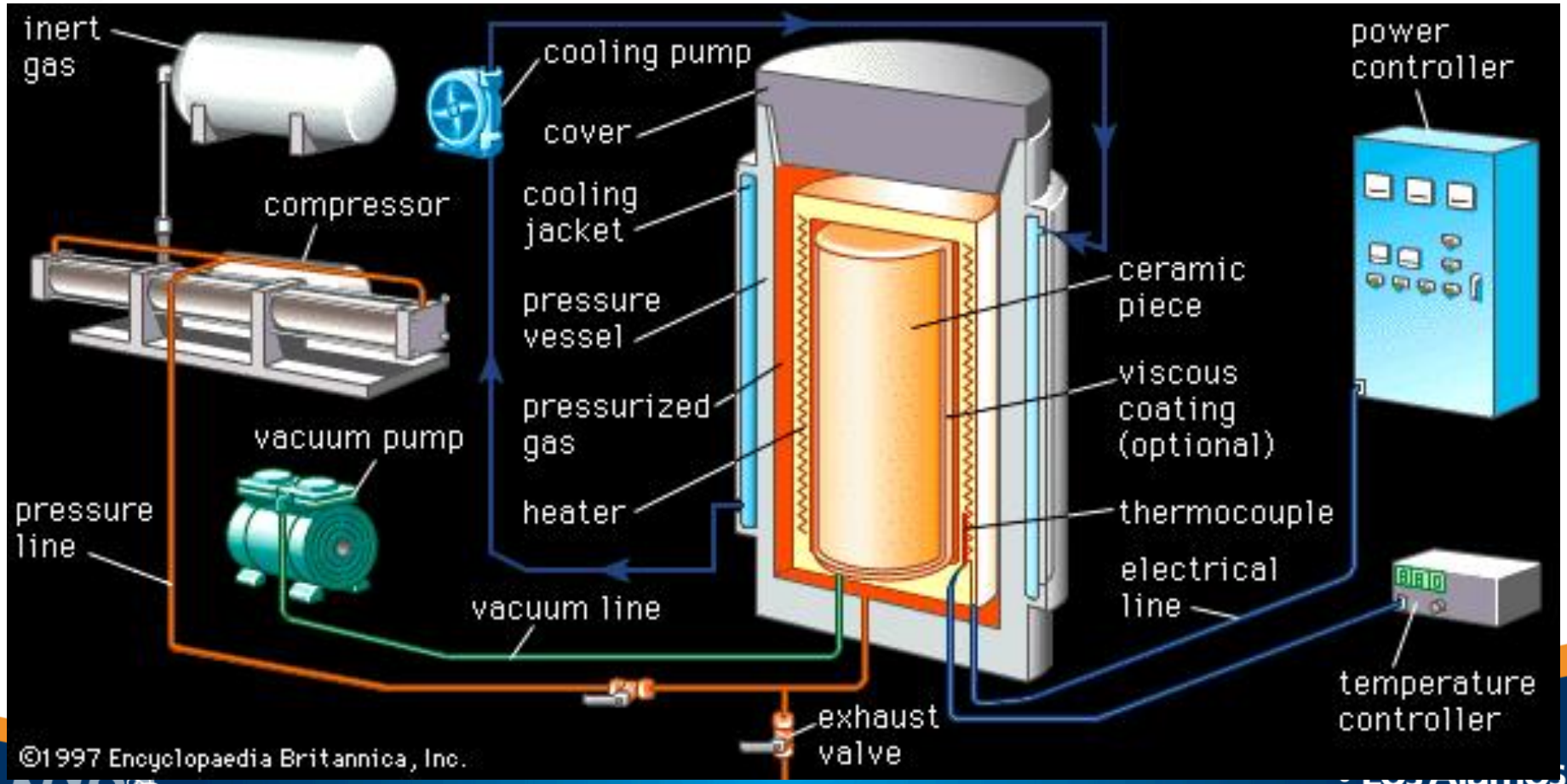
- **Tape Casting** involves placing the slurry on a substrate and then using a sharp straight edge, known as a doctor blade, the slurry is spread across the substrate forming a film of some desired thickness. The green tape is then dried and can be subsequently stacked to increase thickness or build multi-layer constructions, which are then sintered.



- **Sintering** simply stated, is the addition of heat to facilitate densification. During sintering, the green body will exhibit significant shrinkage, which must be accounted for in determining the final product size with respect to that of the green body.



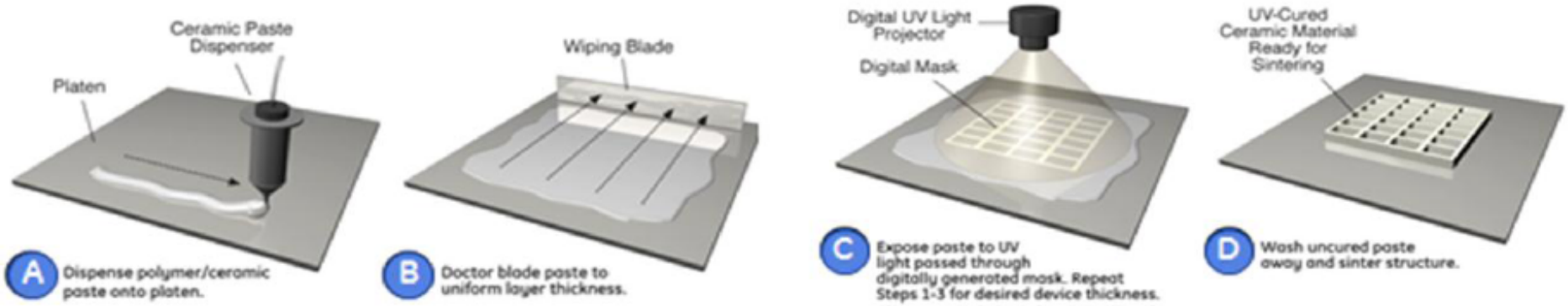
- **Hot isostatic pressing** (HIP) of ceramics is almost identical to HIP performed on metals. The main difference is temperature. Typically, ceramics are HIPed at higher temperatures than metals



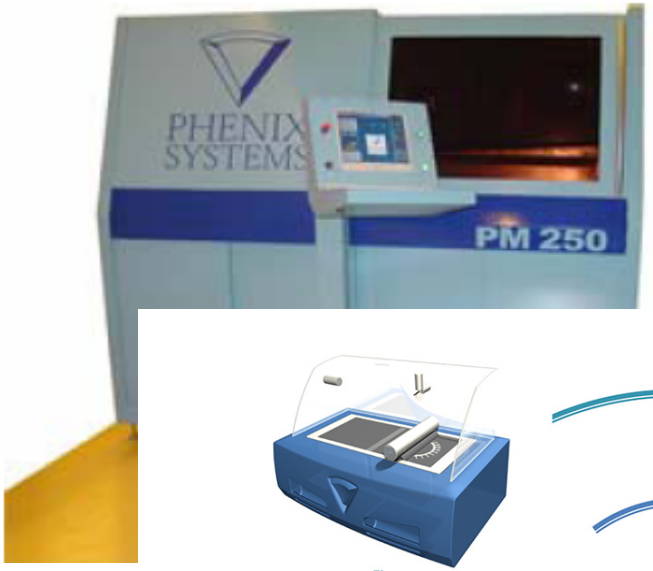
- **Glass forming** involves the use of a ceramic that is a glass former. There are many chemistries of ceramics that will form glasses, but the most common are based on silicates. The desire to use a glass is the ease of shaping. The viscous nature of the glass allows for the formation of complex shapes or high degree of flatness or smooth surfaces. Once a glass is formed and processed into a shape, sometimes an additional crystallization step is performed to impart greater strength.

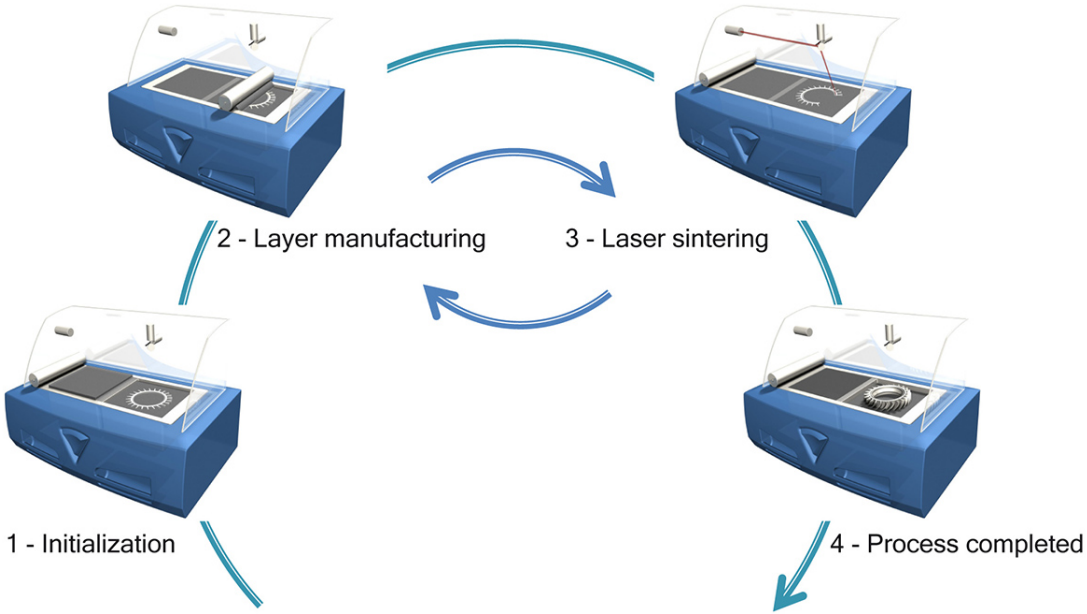
- **Sol-gel processing** is a processing technique that allows for the use of organic precursors for the low temperature production of ceramics, typically allowing for unique chemistries and complex shapes not obtainable using traditional processing techniques. Once again, a slurry, or sol (particles dispersed in a liquid), is used. During the gellation process the slurry can be turned into many different final products, from highly dense traditional ceramics to highly porous materials.

Example of ceramic AM process

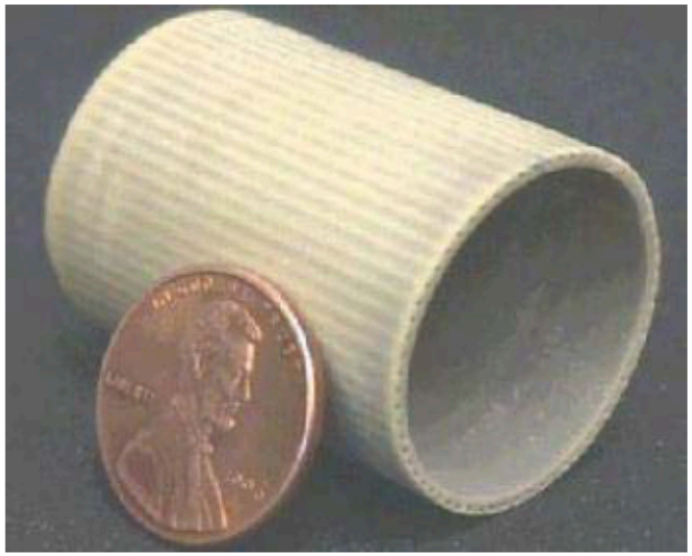


Phenix systems (b



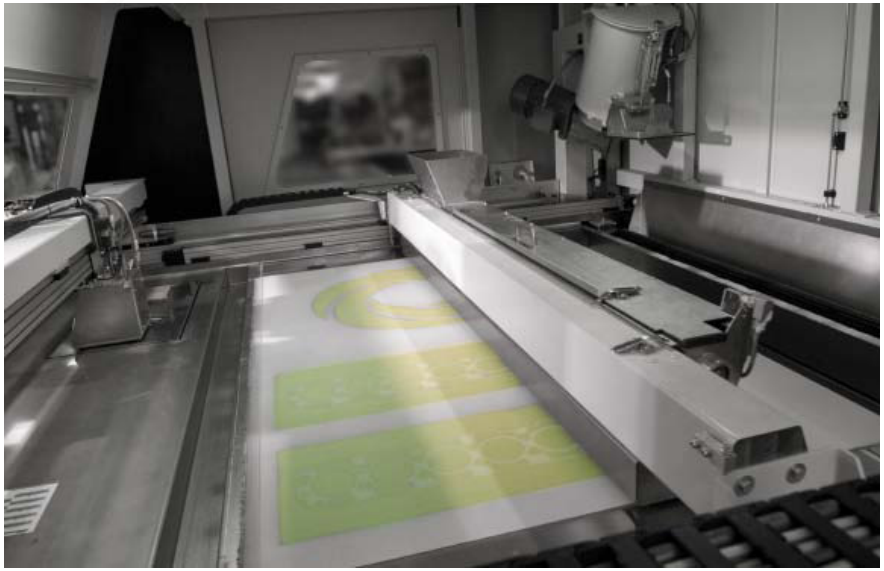


CEM-LAM



- Sheet Lamination Process (tape casting)
- Variety of materials: Alumina, zirconia, silica, oxide/non-oxides, nitrides

3D Systems opens up the world of ceramics with sub-$10k CeraJet 3D printer



Ceramic compatible techniques (first stab)

Technique	Advantages	Disadvantages
Material Extrusion	• Very flexible technology • Widest Range of materials possible	• Binding of 2D structures into 3D structures may be a challenge (depending on approach)
Binder Jetting	• Simple Technique • Amenable to post-processing • May be more amenable to specialty materials	• Limited by binding materials • Powder bed will require large volumes of material in development
Material Jetting		• Powder flow will need to be carefully controlled • May require binder with materials